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Previous research on complex decision making has supported complexity theory predictions concerned with the effects of load stressors on a number of decision-making variables. Considerable data are now available on the effects of load on both simple respondent and complex integrated strategic performance in complex decision-making settings. Data on simpler performance tasks (e.g., hand-eye coordination or other problem-solving tasks) have been collected as well, but typically fall into the category of load effects on simple respondent behaviors. The present research was designed to systematically investigate the effects of load upon both respondent and strategic behavior in simpler tasks. A hand-eye coordination task was specifically developed for this research to permit comparison to data from more complex decision-making settings. Considerable similarities of load effects on performance in the present task to load effects in complex decision-making settings were observed.

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Effects of Load Stressors on Performance in a Multidimensional Visual-Motor Task

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Abstract

Previous research on complex decision making has supported complexity theory predictions concerned with the effects of load stressors on a number of decision-making variables. Considerable data are now available on the effects of load on both simple respondent and complex integrated strategic performance in complex decision-making settings. Data on simpler performance tasks (e.g., hand-eye coordination or other problem-solving tasks) have been collected as well, but typically fall into the category of load effects on simple respondent behaviors. The present research was designed to systematically investigate the effects of load upon both respondent and strategic behavior in simpler tasks. A hand-eye coordination task was specifically developed for this research to permit comparison to data from more complex decision-making settings. Considerable similarities of load effects on performance in the present task to load effects in complex decision-making settings were observed.

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Complexity theory (Schroder, Driver and Streufert, 1967; Streufert, 1978; Streufert and Streufert, 1978) proposes that strategic behavior, measured as differentiation and integration of information in perception and decision making, tends to occur optimally at intermediate information load stressor levels. An inverted U-shaped curve relating environmental stressor variables, such as load, to a number of performance variables (e.g., the use of strategy in complex decision making) is posited. Later versions of the theory (e.g., Streufert and Streufert, 1978) distinguish between stressor effects on simple performance and on complex performance. Simple performance is, for example, represented by respondent behavior (c.f., Streufert, Driver and Haun, 1967), i.e., any effort in which a specific stimulus does lead or should lead to a single specific response. Complex performance includes a number of task-oriented behaviors which utilize several dimensions, often in interaction, in translating information into two or more divergent, but strategically related responses. Later complexity theory predicts quite different relationships between information load stressors and simple vs. complex performance. The prediction of an inverted U-shaped relationship between load stress and complex strategic performance (differentiation and integration) is maintained. The effect of load on simple performance is described as a curve which at first rises

gradually with increasing load, then begins to climb rapidly shortly after the point at which potential complex performance starts to drop off, and finally levels off to a more gradual climb and an asymptote as maximum performance capacity of the system (individual, group, organization, etc.) is reached.

Considerable research testing the propositions of complexity theory has been reported. For example, Streufert and Driver (1967), Streufert and Schroder (1965), Streufert (1970) and Stager (1967) have supported the inverted U-shaped function relating load to measures of differentiation and integration in complex strategic performance. Replications in various cultures and across a number of other tasks have strengthened the theory further. For example, Samuel, Baynes and Sabeh (1978) obtained similar results with anagram problems (c.f. also, Martens and Landers, 1970).

Findings supporting the proposed relationship between load stress and simple performance come from a wide variety of tasks. For example, Quastler and Wulff (1955), in one of the earlier efforts, measured the response of pianists to random printed notes which had to be reproduced on the piano to the faster and faster ticking of a metronome. Using a complex decision making situation, Streufert et al. (1967) obtained measures of simple respondent decision making in response to a number of load levels. In the latter task, subjects were able to make both simple and complex decisions as they saw fit.

Previous research has considered load effects on both simple (respondent) and complex (differentiated/integrated strategic) behavior in complex decision making tasks and other work environments where

multidimensional performance was clearly of value. In addition, data have been obtained on simple behavior (e.g., rote memorization for short-term recall, accuracy of respondent behavior to specific stimuli) in tasks which are less complex (e.g., visual-motor or visual-communication systems, simple learning or simple identification tasks). However, there appear to be no available data on the effects of load upon complex strategic behavior in the latter kind of task environment, i.e., in a simple task. One might argue that lack of research on complex strategic behavior in these somewhat simpler tasks would be appropriate, since multidimensionality which would allow for the use of (strategic) differentiation and integration may not be required. While this may well hold true for some of these task environments (such as simple target identification), other work environments which fit into the general category of problem-solving tasks may, at least at times, require considerable strategic behavior based on multidimensional perception and strategic action. Examples may be the efforts of at least some radar operators, air traffic controllers and others who do more than merely decode, translate and transmit information. Persons in such work environments must often be simultaneously aware of several informational dimensions and must interrelate their dimensional judgments if they are to perform adequately. While these (and related) tasks may be classified as the "problem solving" rather than the "complex decision making" variety, they certainly allow for the utilization of some form of strategy and multidimensionality. Without question, research on the simple performance aspects of these tasks (such as stressor effects on alertness, decoding accuracy, and more) is quite valuable and has been widely pursued. Such research efforts would, however, not provide us with

sufficient information about other important load-stressor to performance relationships. Respondent behavior as a function of load may at times adequately describe total performance quality, particularly when responses can be made in "rote" fashion. However, whenever unusual situations do occur, such performance measurement is probably inadequate. The research reported in this paper is specifically concerned with simple performance (avoidance of errors) and complex performance (utilization of strategy) in response to load for a visual-motor task representing the kind of work environment which persons who must translate input on a visual display into specific action do experience on the job.

As stated above, previous research has clearly demonstrated the reliability of the inverted U-shaped relationship between load stressors and strategic performance in complex decision-making tasks. Can a similar relationship between load and strategic performance be expected in a more simple visual-motor problem-solving task as well: Previous research has not explored a range of load levels and consequent strategic performance in work environments of this nature. Nonetheless, some data may be suggestive. A number of researchers have reported that data obtained from tasks which differ in their complexity show quite diverse load effects. For example, Stager and Zufelt (1972) exposed Ss to a complex decision-making task, but required them to simultaneously perform a tracking task. Significant differences due to load were obtained in the decision-making task, but not in the tracking task. Saito and Tada (1970) compared the effects of sensory overload vs. sensory deprivation on memory processes and motor activity tasks. No differences between task performance decrements were obtained for overload. However, deprivation improved performance in the motor task, but diminished performance in the more complex verbal task. In other research, Saito (1971) has shown

that long-term retention was diminished under overload conditions while motor activity was not. Clearly, none of these researchers has specifically investigated the effect of a range of load stressors on strategic behavior in hand-eye coordination or other problem-solving tasks that would be of interest to the present concerns. With the discrepancies among tasks of different complexity that were reported, however, it appears unlikely that strategic behavior should be affected by load variation in identical fashion across various tasks. A task environment requiring hand-eye coordination efforts was specifically designed for this research. The task is presented at systematically varied load levels to measure both strategic and respondent performance.

METHOD

Twenty-five adult male paid volunteers with a median age of 49.3 (range 23 - 71) participated as individuals in a hand-eye coordination task presented in the form of a video game. Upon arrival at the laboratory, each subject was individually briefed about forthcoming events and his signature on a consent form was obtained. He was then presented with the task.

The Task

A video game task, not unlike Pac Man, was specifically developed for this research.* The game utilizes a series of concentric passageways filled with a number of squares which the subject is to scoop up with a horseshoe-shaped object which he is able to move by operating a handle on a small box placed on the subjects' desk. The matrix of passageways is presented in Figure 1. The subject begins with a score of five points. Scooping up one square adds five points to the subject's score. Moving through one unit of empty space between the squares subtracts one point from the score. In other words, a continuous movement through spaces filled with squares would add 5-1=4 points for each square collected. Moving through spaces where no squares are present would subtract one point for each empty space, including those spaces occupied previously by squares. In other words, to obtain as high a score as possible, it is useful to avoid moving through blank spaces, i.e., to move so that as many squares as possible can be picked up in one continuous series of moves. Movement

*The task was generated by an Apple II Plus Computer utilizing a floppy disk program developed specifically for this research by the Wise Owl Workshop.

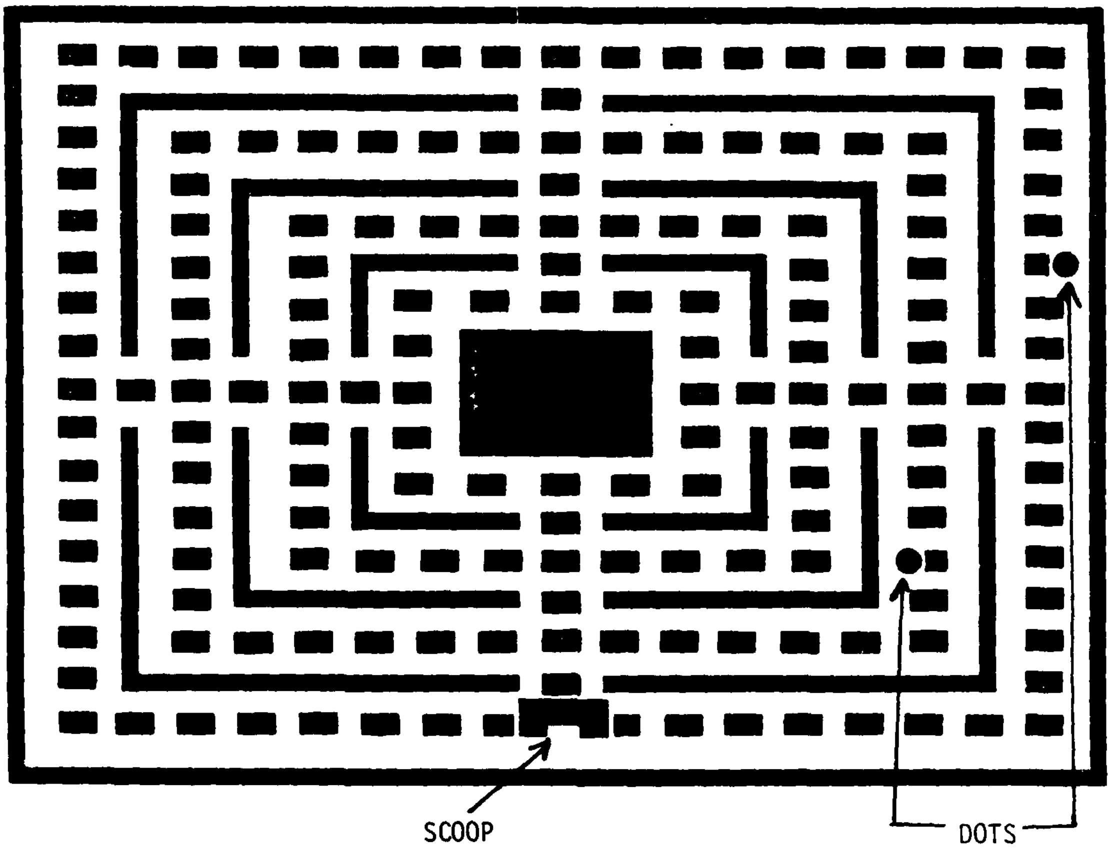

FIG. 1. Task matrix.

is possible only through passageways. Movement across solid lines is not possible.

In addition to the squares, from one to eight dots (differently colored) can appear in the matrix shown in Figure 1. The dots move randomly along the passageways of the matrix, reversing their direction (again randomly) from time to time. The dots are to be avoided: colliding with them is considerd an error, costing the subject 100 points for each collision. A collision removes the dot to a different random position in the matrix so that a second collision due to the same error does not occur.

The computer program permits the experimenter to systematically vary a number of characteristics which apply during any one task period. The characteristics which can be modified are: (1) the speed of movement for both the subject's scoop and the dots which the subject is to avoid. Speed can be increased or decreased in four equal interval steps; (2) the number of dots on the screen (varying from one to ten); and (3) a score (displayed on the screen throughout the task period) representing an experimenter-selected value indicating either the average score obtained by other subjects on their first try or (optionally) the highest score obtained by any subject. In addition, the experimenter is free to select the number of task periods which are to be employed in the research effort. Each period lasts until the subject has successfully scooped up all the squares from the matrix on the video screen. The subject's current score is continuously displayed at the bottom of the screen. As stated before, the score starts at +5 and increases as more and more squares are captured. It decreases with collisions

with dots and movement through blank spaces. The score may become a negative value if the subject moves through blank spaces 2.5 times more often than squares are captured or if the subject repeatedly loses blocks of 100 points by collision with dots.

Instructions to Subjects

Subjects are instructed via video tape in detail about the operation of the task. They are reminded to avoid collisions with white dots. They are also told about the loss of points created by moving through blank spaces. They are further asked to try to do as well as possible, to avoid letting scores drop below zero, and to try hard again during the next task period if they are not as successful as they might wish during a previous period. While the subjects are presented with the consequences of failing to use strategy, they are not told what strategy should be used to obtain maximal scores. Instructions are moderately challenging, and can be considered somewhat below the challenge and competition level induced by Dembroski, MacDougall, Shields, Petitto and Lushene (1978). The level of challenge and competition selected for these instructions was based on work environments rather than experimental environments. The subjects are told to expect different speed levels and different numbers of dots to be avoided from one game period to another. The actual number of periods that will be played is not specified in advance.

Load Manipulation

Subjects were initially given a practice try to familiarize themselves with the task and eliminate or decrease the potential effects of previous experiences with video games. For the practice task, speed was held at

level 1 (low). Only one dot was presented in the matrix. After completing this task period (and after all other subsequent periods), subjects responded to a number of seven-point scales (manipulation checks). After completing the scales, a subject was asked whether he was ready to try the task again. All subjects responded positively in all cases.

All subjects participated in four task periods following the practice period. The number of dots, representing the load manipulation, was systematically varied for these four periods. Either 2, 4, 6 or 8 dots were placed into the matrix. From a number of random sequences for the load manipulation, 25 were chosen (via a counterbalancing procedure) to assure that specific load levels would not occur inordinately often at any sequence position. Speed for all four task periods was held at level 2 (moderate). Subjects were not aware of what their next load level would be until the matrix with the relevant number of dots appeared on their screen at the beginning of the task period.

A read-out at the bottom of the video-screen informed subjects during the first (practice) period that the average score obtained by other subjects during their first try had been 435. That score level was rather easy to achieve and was surpassed by all but two of the subjects in this research. For the following four task periods, the subscript on the screen indicated that the highest score obtained by any subject so far had been 898. None of the subjects achieved or surpassed that score.

The performance of all subjects in response to tasks at all load levels was video-taped for later analysis. Data were based on performance scores for the four periods following the practice period.

Scoring the Task Performance

1. Strategy. Any movement of the scoop directed by a subject which clearly facilitated collecting squares that at a later point could only have been reached by moving through blank spaces was assigned a score of +1. For example, let us assume that a subject had previously collected all but three squares in one of the passages of the matrix (and had to leave the last three standing because he was "chased" by one of the dots). If he later found himself (while collecting other squares) at the nearest point to those three dots, he would receive a point for collecting those three squares at that time rather than waiting until a later time when he would be further removed from those squares across blank space.

Any movement which clearly left squares in the passageway or next to the passageway of a subject's scoop (with no interference by a dot), at a point where they would have to be picked up later at a cost of moving through blank spaces, was assigned a score of -1. For example, if a subject initially erased all squares in the outside passage and then proceeded to the next set of passages, counting from the outside, without picking up the three (one was removed by moving from the outermost to the next passage set) squares on the cross passages, he would have to return later through blank areas to scoop up those squares. Such a set of moves would be unstrategic and would result (if all three squares were left standing) in a score of -3. Scores were summed for each of the task periods.

2. Error scores. Each collision with a dot was scored as an error. Dots could be avoided by: (1) selecting passageways for activity where no or very few dots were currently present, and (2) reversing direction far enough in advance of an approaching dot to safely turn into another

passageway at the next intersection. Reversing through blank spaces was much less costly in terms of subtracted scores than colliding with a dot. Avoidance of errors was considered successful respondent (more simple) behavior while obtaining positive and avoiding negative strategy scores was considered a form of more complex performance, akin to the differentiation/integration measures obtained in decision making tasks.

3. Final Scores. The final score for each task period of each subject was calculated by the computer on the basis of the total positive and negative scores obtained during the task (see above). The final score was the last score displayed on the screen, after the subject captured the last square remaining in the matrix. That last score was prominently displayed on the screen for about ten seconds after the task period had ended so that each subject would be aware of his level of accomplishment.

Final scores reflected both the degree of strategic performance (avoidance of returning to uncollected squares through blank spaces) and absence of errors, i.e., acceptable moderate risk levels resulting in no or few collisions with dots. A large number of errors would affect the final score more significantly than absence of strategic behavior.*

*A greater impact of a considerable number of errors on the final score was chosen since errors in simple respondent decision making would be likely to have considerable immediate impact on performance. While strategic performance would be likely to enhance adequate respondent performance, strategic performance without adequate respondent performance would not be useful in most tasks.

RESULTS AND DISCUSSIONS

Manipulation Check

Following each task period, subjects were asked to respond to seven-point scales concerned with the previous task period. Among these scales were questions asking subjects how difficult their task had been during the previous period and how difficult they thought the task might have been for the average person, had he or she engaged in the task. Responses to both seven-point scales were analyzed with a two-way between ANOVA technique. Factors were self/other (two levels, within) and task periods (four levels, within). A significant main effect ($F = 23.25$, 3/72 df, $p < .001$) was obtained for task periods. Difficulty increased in linear fashion for both self and other with increasing load. The main effect for self vs. other ($F = 3.82$, $p = .06$) and the interaction effect ($F = 1.21$) did not reach significance. An increase in perceived difficulty with increasing load was expected and was considered evidence for appropriate manipulation of the load variable.

Data Analysis

Data for the practice period were not analyzed. Data analysis was based on load levels 2, 4, 6 and 8 during the randomized task periods following the practice period. Separate ANOVA (one way, four levels, within) procedures were employed for the three dependent variables. A significant F ratio for Strategy ($F = 19.57$, 3/72 df, $p < .001$) was obtained. Increases in load from 2 to 8 dots in the matrix resulted in a decrease in strategic behavior. That decrease was slight (and significant) for comparisons of load 2 and 4, but became increasingly larger (and significant) for comparisons between loads 4 and 6 and loads 6 and 8. While scores for

loads 2 and 4 represented average values above zero, loads 6 and 8 represented average strategy values below zero, i.e., subjects on the average made primarily strategic errors. The results are presented in graphic form in Figure 2.

Data analysis for errors (the number of times during any one playing period subjects' scoop collided with dots on the screen) indicates increasing numbers of errors with increasing load ($F = 57.51$, 3/72 df, $p < .001$). The data are presented in Figure 3. One might be tempted to explain this finding as a probability function of the number of dots on the screen. Collision with eight dots would be four times as likely as collision with two dots. The data, however, do not support such a simple relationship. The mean value of collisions for load 2 (1.40) multiplied by four would predict 5.60 collisions for load 8. The actual value obtained under load 8 of 9.44 appears to be considerably higher. Another finding which would argue against a simple probability interpretation are the values for loads 4 and 6 which are relatively similar to each other (3.96 for load 4 and 4.80 for load 6). It appears that a major step in errors was reached between the load levels 2 and 4 and yet another major step was reached between load levels 6 and 8. It may be interesting to remember that the increase in load from level 6 to level 8 passes the "magic number 7" (c.f. Miller, 1956). In other words, the subjects may at that point have lost their overview of the dots present in the matrix.

The analysis for Final Scores produced a similar result as that seen for the Strategy analysis. Final scores obtained by the subjects tended to be positive values for load levels 2 and 4, shifting to negative values for load levels 6 and 8. The F ratio for the final score analysis was again

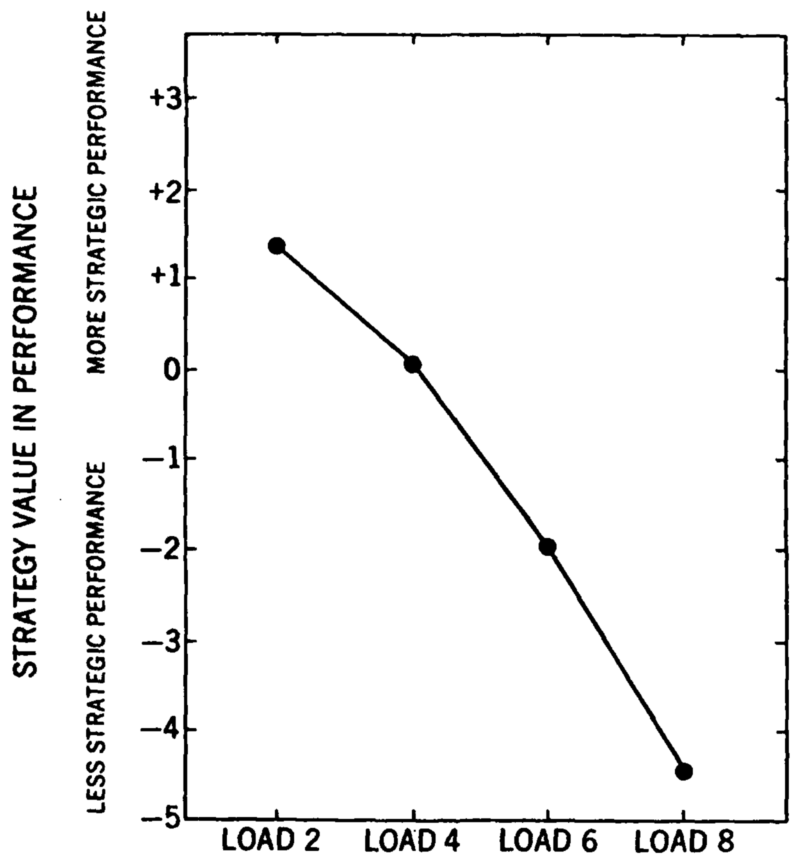

FIG. 2. Effects of four levels of load on strategy in task performance.

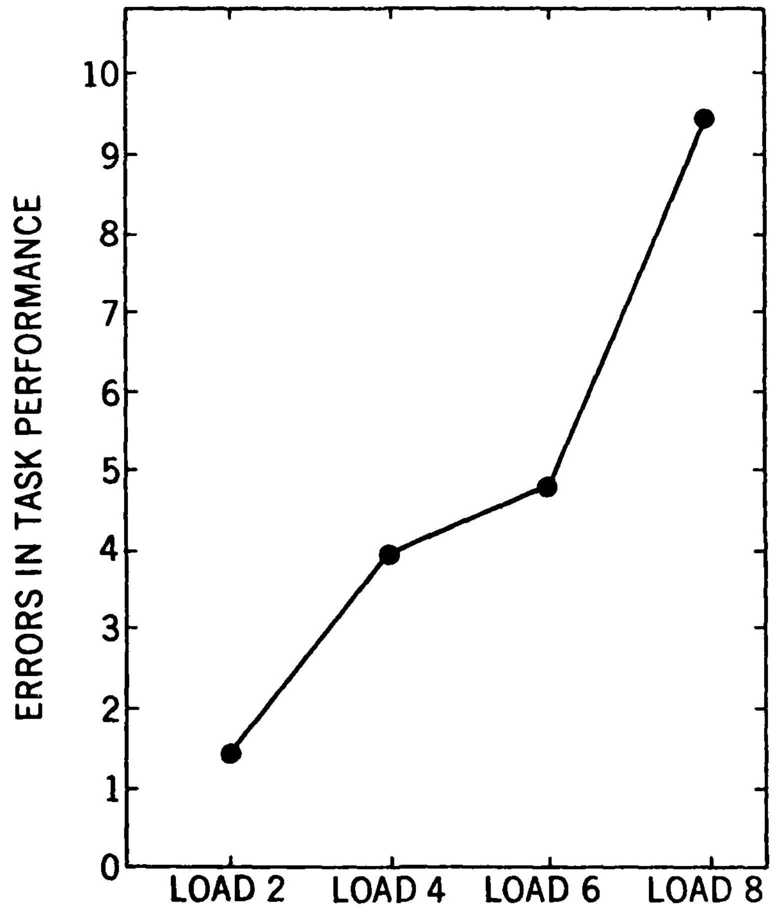

FIG. 3. Effects of four levels of load on errors in task performance.

significant (F = 48.11, 3/72 df, $p < .001$). The data are presented in graphic form in Figure 4. In contrast to the strategy analysis, however, all comparisons among load levels produced significance. Clearly the errors made by subjects affected the final scores, at least in the load range between 2 and 4.

Implications

The data suggest that increasing load in a visual-motor problem-solving task of the kind employed here does diminish strategic performance. This finding contrasts to some degree with the inverted U-shaped functions obtained in complex decision-making tasks. We should be aware, however, that load in a complex decision-making task is something qualitatively different than load in the present task. In the former, we are dealing with information load: reports of events which are necessary for substantive functioning in the complex task. In their absence, it is difficult to make decisions, in particular, it is difficult to make strategic decisions which require an overview based on multiple information. In the present environment, load was defined as the number of stimuli (dots) which were to be avoided. Surely the dots on the screen did provide information of a kind, yet it was not information which was required to complete the task. Task related activity could continue. Strategic behavior could continue in the absence of many loading stimuli, creating a task environment which is hardly comparable to the relative deprivation (c.f. also Suedfeld, 1978) experienced by participants under low load conditions in the complex decision-making tasks employed by Streufert and associates (e.g., Streufert, 1970). As a result, one might expect only the part of the inverted U-shaped curve which has been

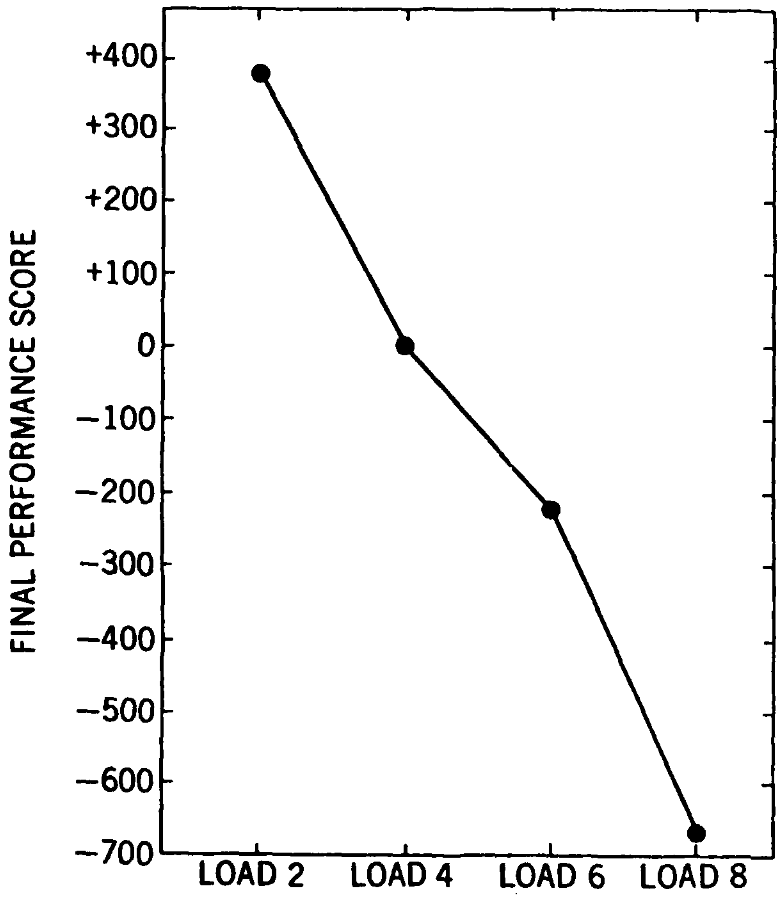

FIG. 4. Effects of four levels of load on the final performance score.

reported for the range between optimal and super-optimal load levels: a first gentle and then more rapid downturn in strategic quality. Viewed from this vantage point, the results obtained in the present visual-motor task are quite similar to those obtained in previous research on complex decision making.

Another relationship of interest exists between the error score in the present research and respondent decision-making data obtained from complex decision-making tasks. Both have been (above) described as reflecting components of simple forms of task related activity. Let us take a closer look at respondent decision making. A respondent decision (usually in response to incoming information in complex decision-making tasks) considers only one stimulus at a time. A response is made to that stimulus even though other information which could or should bear on the situation (and the decision) is present. Respondent behavior is, by definition, non-integrative, unidimensional, and non-strategic. Similar behavior on a somewhat different plane takes place when subjects make "errors" in the present task. Subjects had been instructed to capture (scoop up) squares from their screen. Attending to both the squares and to the dots takes consideration of two dimensions. It appears that with increasing load stressor levels, subjects' focus became less multidimensional. Responses to oncoming dots were slowed, i.e., risk levels appeared to be on the increase. In several cases, the subjects no longer responded at all to the threat from an oncoming dot and accepted the loss of 100 points, even though a reversal of direction through now blank spaces would have been much less costly. It appears, then, that respondent actions to the

task requirement of capturing the squares became more pronounced with increasing load. To compare respondent behavior in this task with respondent behavior in complex decision-making tasks, we may consider the number of errors made as a rough equivalent of responding to only one segment of the task requirements at the cost of another task dimension. The number of errors made, in other words, would reflect the degree to which respondent behavior was present.

If we consider the data from such a point of view, it would appear that respondent behavior increased from load levels 2 to 4, with less of a rise from levels 4 to 6, followed by a considerable increase in respondent activity between load levels 6 and 8. The lesser increase occurred at a point where (according to the data on strategy discussed above) strategic behavior had showed its first major drop. Previous research in complex decision-making settings (e.g., Streufert et al., 1967) had suggested that persons may strain to produce strategic behaviors at such a point, resulting in a temporarily diminished rise in the curve for respondent actions. The finding of a decreased degree of rise in the curve for errors may well be due to such a strain toward strategic behavior.

Generally, then, it appears that there may be considerable similarities in performance scores for more complex (strategic) behavior and for more simple (respondent) behavior. Why, then, have other researchers obtained results (in somewhat different task settings and without systematic analysis across various load conditions) which suggest differences? For the present research, a number of design characteristics

were included which permitted comparison between the two task levels (e.g., systematic variation of load, possibility of strategic behavior, etc.). As a result, it was possible to meaningfully compare the task levels. On the other hand, however, the tasks did have similarities that may introduce boundary variable (c.f. Fromkin and Streufert, 1976) conditions which would limit application of the present research. While we may be able to say that similar load effects occur in complex decision-making tasks (e.g., high level strategic operations) and hand-eye coordination tasks based on multidimensional information characteristics (e.g., flight control operations), these similarities may not exist if comparisons are made between complex decision-making tasks and simple problem-solving efforts based on unidimensional operations (e.g., target identification). Similarly, the performance scores (Final Score) obtained in this research may be useful only under conditions which are paralleled by the present research design. As stated above, the selection of scoring procedure for the "final score" assumed that absence of errors was somewhat more important than utilization of strategy. In the real-world outside of the laboratory, for example, a hit from an enemy rocket would make any future strategy useless since it may never take place. Once "survival" (absence of such hits) would be guaranteed, however, primary emphasis on strategy could become very useful. For any applied setting where errors can be less damaging (e.g., where hits from an opponent can be absorbed with minimal damage to one's operating capacity), the score values in this task may have to be modified to allow application to real-world problems.

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